Willingness-to-Pay Effects of Gene Drive Insect Use for Agricultural Pest Management in Diverse U.S. Market Applications

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Abstract

Biotechnology advances and CRISPR/CAS9 editing abilities may soon add a novel option known as a 'gene drive'. In a gene drive, preferentially inherited traits could reduce or eliminate populations of pest species or inhibit their ability to spread crop disease. However, cost savings in pest management must be weighed against potential demand impacts of genetically engineered insects in growing environments. This may be particularly important for organic production, regulation, and certification value. In this study, we administer an online survey to a nationally representative probability sample of 1,018 U.S. adults, gathering data on gene drive attitudes and impacts on willingness-to-pay for two products which are host crops for insects under current drive research.

Keywords Agricultural biotechnology, gene drives, pest control, consumer welfare

Introduction

When new, invasive species threaten agricultural crops, how can these threats be effectively and acceptably managed? Biotechnology advances and CRISPR/CAS9 gene editing capabilities may soon facilitate a novel approach with the development of genetically engineered insects. This approach could have substantial applications in agriculture, addressing devastating pest problems while reducing environmental damages from pesticides. A new strategy some scientists are pursuing is called a 'gene drive,' using a gene editing technology called CRISPR/CAS9 (Barrangou 2014; NASEM 2016). With this approach, scientists may be able to modify the genes of insect pests to prevent transmission of serious crop diseases or reduce their populations by disrupting normal reproduction (Hammond et al. 2016). Gene drive systems are distinct in that engineered modifications could be intentionally spread through entire populations of a pest species, as modified individuals pass on genetic changes that are inherited by up to 100% of their offspring (see: Burt (2003), Sinkins & Gould (2006)).

Recognizing the potential for unintended consequences with such a powerful technology, experts and funders have called for precaution and early engagement with the public (NASEM 2016; Emerson et al., 2016). The complex environment into which they may be deployed is fraught with challenges in terms of technical difficulty, public opinion, governance and regulatory hurdles, as well as need for broad cooperation across geographic landscapes where drive insects may travel (Baltzegar et al., 2018; Kuzma et al., 2018). Public views on gene drives are unlikely to be independent from previous controversy involving genetically modified organisms (GMOs) in food supplies (Baltzegar et al., 2018; Costa-Font et al., 2008). However, distinct components of gene drives require specific investigation into potential net consumer reactions. In doing so, researchers can help inform developers and policymakers at early stages about the potential downstream impacts of these novel approaches vis-à-vis other pest management alternatives. For example, the genetic manipulation of pests instead of food products may potentially reduce consumer apprehension. However, the intentional – and potentially uncontrolled – spreading of genetic modifications through pest populations, rather than (somewhat) field-isolated genetic material in GM crops, may increase public concern, as has been expressed by gene drive researchers and evaluators (NASEM 2016).

The objective of this study is to investigate the demand effects of gene drive insect use in growing environments against other chemical and biotechnological approaches to manage destructive invasive agricultural pest species. Especially given impending implementation of the National Bioengineered Food Disclosure Standard, our study provides an important perspective on public values and preferences for mobile genetically engineered organisms in growing environments. Through a discrete choice experiment embedded within a nationally representative probability sample of 1,018 U.S. adults, we focus our analysis on willingness-to-pay for fresh and processed fruit products. We believe this is the first study of any genetically engineered insect's impact on consumer demand for an agricultural good. We further examine the impact of gene drive insects on attitudes about USDA-organic certification and the premium consumers are willing to pay for USDA-organic pest management regimes, providing important insights for the growing, multi-billion dollar organic industry. Lastly, we explicitly measure the relative effect on consumer utility and willingness-to-pay of crop genetic modification vs. gene drive insects for pest damage mitigation.

Background

While no gene drive insect has been released in the environment to date, researchers have actively pursued this strategy for some time. One of the first gene drive attempts in an agricultural pest was to control Huanglongbing or citrus greening, a bacterial disease (*Candidatus liberibacter* spp.) which has devastated the $3.3 billion U.S. citrus industry, with declines of 21.5% and 25.8% in Florida bearing acreage and yield since the disease was found in 2005 (USDA 2017a). The bacterium is vectored by the Asian citrus psyllid (*Diaphorina citri*), an invasive species from East Asia. The proposed gene drive, funded by a grant from the US Department of Agriculture (Turpin 2012), would have spread a strain of the citrus psyllid that would no longer be able to transmit the bacterium. This type of gene drive is referred to as a *replacement drive*, in which genetic modifications permeate through an insect population over time and leave an altered version of the pest species which remains in the environment.

In another application, researchers funded by the USDA (Li and Scott, 2016), and separately by grower associations (Buchman et al., 2018), are seeking to design a *suppression drive* for Spotted Wing Drosophila (*Drosophila suzukii*), an invasive species in the United States that dramatically increases control costs and causes extensive damage to ripening berry and cherry crops worth over $4 billion in 2016 (Asplen et al., 2015; USDA 2017b). Where the suppression drive spreads, a trait could be passed that inhibits reproduction of the pest, leading to eventual population collapse (Burt 2003). Given these first investments in gene drive target pests, we focus our analysis on fresh blueberries and orange juice to provide the most relevant data to inform the current debate.

Given the commercial nature of agricultural applications, ex-ante consumer evaluations are crucial to project demand-side effects of gene drive insects. Building on the simplified stylized framework outlined by Mitchell, Brown, and Roberts (2018), if gene drives work as intended, marginal costs of pest management would significantly decline in crop host environments. This is characterized by a welfare-increasing expansion of the supply curve. However, ignoring demand-side effects would be highly naïve in a context of polarized debates on genetic modification in agriculture and growing public interest in production practices. Negative consumer reactions could partially or significantly attenuate benefits from cost reductions. While we do not attempt to estimate total surplus changes across the system due to lack of data on projected supply curve shifts from major pest removal, we will attempt to project shifts in demand which will drive these surplus changes to inform ex-ante release decisions and which may have ambiguous impacts on consumers and producers alike.

In addition, heterogeneous demand and segmented markets for target fruit products may – potentially – disproportionally impact markets with high sensitivity to genetically engineered organisms in growing environments. This includes areas under certified organic production, where, for example, control of Spotted Wing Drosophila infestations is possible but difficult and costly due to limited effective control methods available (Van Timmeren and Isaacs, 2013). As a gene drive approach could decrease pest and disease pressure without the need for pesticide applications, this could provide benefits to organic production systems. Consumer studies may be particularly relevant for certified organic growers to understand the nature of market risk with drive insect releases, as some authors (e.g. Reeves and Phillipson (2017)) have expressed concern about the impact of genetically engineered insect presence on certification retention under certain release contexts and the role of public reaction. Under current regulations *7 CFR § 205.105:*

> *"Allowed and prohibited substances, methods, and ingredients in organic production and handling",* excluded production methods include: *"A variety of methods to genetically modify organisms or influence their growth and development by means that are not possible under natural conditions or processes and are not considered compatible with organic production. Such methods include cell fusion, microencapsulation and macroencapsulation, and recombinant DNA technology (including gene deletion, gene doubling, introducing a foreign gene, and changing the positions of genes when achieved by recombinant DNA technology). Such methods do not include the use of traditional breeding, conjugation, fermentation, hybridization, in vitro fertilization, or tissue culture (7 CFR § 205.2-Terms defined)"*.

Further, USDA Policy Memos on the National Organic Program have detailed responses to questions about incidental adventitious presence of genetically modified material in the crop:

> *"The NOP regulations prohibit the use of excluded methods (i.e., "GMOs") in organic operations. If all aspects of the organic production or handling process were followed correctly, then the presence of a detectable residue from a genetically modified organism alone does not constitute a violation of this regulation… As long as an organic operation has not used excluded methods and takes reasonable steps to avoid contact with the products of excluded methods as detailed in their approved organic system plan, the unintentional presence of the products of excluded methods should not affect the status of the organic operation or its organic products"* (McEnvoy [USDA-AMS], 2012).

Authors Reeves and Phillipson (2017) have argued that the cooperation of organic producers within mass release programs of GM insects, as well as the implicit assumption of full geographic coverage for pest eradication, would challenge basic tenants of reasonable exclusionary practices to avoid GMOs. This may be coupled by direct grower associations, which may include organic members, actively funding of GM insect research; for example, in current gene drive Spotted-Wing research (Buchman et al., 2018).

However, even if the organic standard is determined legally secure in the short term, consumer perception of the product attributes denoted by the USDA-organic label may be even more important than final legal decisions about standard guidelines. Recent research has found USDA-organic and 'Non-GMO Project' labels are strong substitutes in apples (McFadden and Lusk, 2017), so it is unclear if this 'GMO aversion' also includes genetically engineered insects in the growing area. In the United States, considerable effort and expense has been invested to achieve goals for 'co-existence' between conventional (GM and non-GM) and certified organic production systems (Greene et al. 2016). Given tension already surrounding the use of genetically engineered crops in close proximity to organic production environments, these niche market demand effects may merit attention from policy makers in discussions about gene drive insect release, especially if these attitudes translate to a strong contraction in WTP for certified organic products when drive insects are present.

Methods – Survey Design

In this study, we employ a discrete choice experiment (DCE) to investigate consumer responses to gene drive insect use in area-wide pest management regimes. The DCE is embedded within a larger web-based survey fielded in October and November 2017 through the survey firm GfK's KnowledgePanel®, a representative probability sample of U.S. adults, which resulted in 1,018 completes for analysis.

All respondents receive a basic explanation of gene drive technology, illustrations of the citrus psyllid and spotted wing applications described above, and respondents freely selected from seven frequently-asked-questions (full wording in Appendix). Respondents then reported attitudes on various contexts of gene drives for agricultural pest control and specific views on use in organic agriculture. The willingness-to-pay (WTP) portion was only completed by respondents affirming household purchase of fresh blueberries or orange juice in the last six months[1]. From 1,018 total respondents, we draw WTP data from 457 fresh blueberry consumers and 408 orange juice consumers who completed a (single) DCE. Following convention to reduce potential hypothetical bias in WTP estimates, a cheap talk script[2] was adopted in the DCE introduction (Lusk 2003).

For both products, we include attributes of gene drive insect presence in the growing area, whether the plant is genetically engineered to resist pests, price, and pest management, which includes a high conventional spray level, low conventional spray level, and the USDA-organic seal. Product attributes and corresponding levels are outlined in Table 1. Respondents could choose between two product options or to 'not purchase either one of these products'. A D-efficient design powered to estimate main effects and interaction between gene drive insect presence and other current pest management practices was generated and fielded to a pretest sample via Amazon MechanicalTurk (n=300) to validate the instrument. Given current organic program regulations, to keep choices realistic we excluded the possibility of a genetically modified plant appearing in the same alternative as the USDA-organic seal. Priors from pretest

[1] In the case of households purchasing both products in the last six months, respondents were randomized at a ratio of 2:1 to the blueberry (v. orange juice) DCE. This is based on pretesting in Amazon MechanicalTurk (n=300, within US) indicating more frequent sole consumption of orange juice vs. blueberries and a desire to achieve roughly equivalent DCE sub-sample sizes. Consumption of blueberries was somewhat higher in the GfK sample than the Amazon MechanicalTurk pretest sample.
[2] Cheap talk script within the DCE introduction: "When making your choices, please consider the price of the product carefully compared to your household's grocery budget. (In questions about hypothetical purchase choices, people often tend to overstate their willingness to purchase some products.)"

estimation were used to generate a more efficient design for the main round (Huber and Zwerina, 1996), which yielded a total of 18 choice tasks. These were optimally blocked into two groups of nine choice sets for each respondent to avoid survey fatigue.

Table 1: DCE Attributes and Levels for Fresh Blueberries and Orange Juice products

Attributes	**Levels**
Gene Drive Insects	Present in the growing area to control pest damage; Not present in the growing area
Plant Type	Genetically modified to resist pest damage; Not genetically modified
Pest Management Regime	USDA-Organic [seal shown]*; Low Conventional Spray Level; High Conventional Spray Level
Price	
Fresh Blueberries ($/pint)	1.06; 2.12; 4.25; 5.31
Orange Juice ($/half-gallon)	2.95; 4.07; 5.21; 6.34

Note: **Plant Type Wording** - "The plant and fruit are genetically modified to resist pest damage" [Genetically modified], "The plant and fruit are not genetically modified" [non-genetically modified]. **Pest Management Regime wording** – *Blueberries*: "Conventional insecticides applied only when pest populations are high" [low conventional spray]; "Conventional insecticides applied every five days for several weeks while fruit ripens" [high conventional spray] – *Orange Juice:* "Conventional insecticides applied in the field 1-2 times per year" [low conventional spray]; "Conventional insecticides applied in the field 11-14 times per year" [high conventional spray]. Low v. high spray regimes represent predominate pest management regimes before and after the arrival of spotted wing (blueberries) or citrus psyllid (orange juice). *Due to USDA-organic regulations, to keep the choice tasks realistic the organic attribute was restricted to never appear in the same attribute set as a GM plant.

Econometric Model

Discrete choice models are grounded in random utility theory, allowing researchers to estimate the WTP for attributes describing product profiles in an experimental setting. This follows the Lancastrian concept of utility, where Lancaster (1966) argues that utility is not necessarily derived from a good itself; rather, utility is gained from the individual attributes composing a good. In this context fresh blueberries and orange juice are viewed as a collection of production and quality attributes which are heterogeneously valued by consumers. We use the DCE approach for several reasons. First, because gene drive insects are not present in growing systems and thus, barring the use of deception, a revealed preference elicitation method such as experimental auctions is not feasible without deception. Second, DCEs are shown to have design advantages over other stated preference methods, such as contingent valuation, by more closely simulating a real purchasing scenario (Lusk and Hudson, 2004).

Central to the idea of random utility theory is the assumption that economic actors seek to maximize their expected utility subject to the alternatives, or choice sets, they are presented. Based on Manski (1977), an individual's utility is a random variable because the researcher has incomplete information. In a choice experiment, an individual *i* maximizes utility attained from an alternative *j* at choice scenario (or time) *t*. Utility is decomposed into a deterministic [$V(\boldsymbol{X}_{ijt})$] and stochastic element (ε_{ijt}), represented here as:

(1) $U_{ijt} = V(\boldsymbol{X}_{ijt}) + \varepsilon_{ijt}$

When an individual faces a choice between two alternatives *j* and *k*, he or she is assumed to optimize utility such that probability of choosing *j* is:

(2) $\pi_{it}(j) = Prob\{V(\boldsymbol{X}_{ijt}) + \varepsilon_{ijt} \geq V(\boldsymbol{X}_{ikt}) + \varepsilon_{ikt}\ ; j \neq k\}$

In this context, $\boldsymbol{X}_{ijt}$ is a vector of fresh blueberry or orange juice attributes and ε_{ijt} is the random error term iid over all individuals, alternatives and choice situations (Revelt and Train 1998). The deterministic component of utility $V(\boldsymbol{X}_{ijt})$ is assumed to be linear in parameters, where alternative *j* is a compilation of price, whether the plant is genetically modified, presence of gene drive insects in the growing environment, certified organic pest management (vs. high frequency conventional spraying), and low (vs. high) frequency conventional spraying. The experimental design was also powered to allow measurement of the interaction between gene drive insect presence and pest management practices, which provides critical insight into potential erosion of the value of certified organic production. The functional form for the deterministic component can be expressed as:

(3) $V_{ijt} = \beta' \boldsymbol{X}_{ijt}$

In this context $\boldsymbol{X}_{ijt}$ is a 7 x 1 vector of product attributes,

$\boldsymbol{X}_{ijt} = [Price_{jt},\ GM\_Plant_{jt},\ GD\_Insects_{jt},\ Organic_{jt},\ Low\_Conv\_Spray_{jt},\ (Organic * GD\_Insects)_{jt}, (Low\_Conv\_Spray * GD\_Insects)_{jt}]$.

The parameter vector β is to be estimated. The β's are utility parameters to be estimated, which are initially assumed to be constant across individuals in a standard conditional logit model. This assumption of homogenous preferences for attributes across consumers may be unrealistic if tastes and preferences differ across individuals. Given the likely heterogeneity across consumers, we employ a random parameters, or mixed logit model to examine drivers of marginal WTP differences. Using maximum simulated likelihood, mixed logit models (McFadden and Train, 2000) continuously estimate heterogeneous preferences within a sample population by adjusting the coefficient vector such that, for individual *i*, $\beta_i = \bar{\beta} + \sigma\lambda_i$, where $\bar{\beta}$ is the population mean, and σ represents the standard deviation of the marginal distribution of β. λ_i is an unobserved individual-specific random disturbance, which is normally distributed with mean zero and a standard deviation of one. The conditional logit and mixed logit models are interchangeable when $\sigma = 0$. While price and attribute interaction terms[3] are fixed, coefficients for non-price attribute main effects are assumed normally distributed. We test specifications of independent and correlated coefficients to relax the assumption of independence of irrelevant alternatives (IIA), which is generally regarded as too restrictive and a key driving motivation among researchers to employ mixed logit models.

By taking the ratio of estimated coefficients, we can derive willingness-to-pay (WTP) estimates of the marginal rate of substitution between price and non-price attributes. The confidence interval for WTP estimates are commonly estimated via bootstrapping or the delta method; however, as Hole (2007) found these to yield similar results we simply opt for the delta method[4]. The coefficient on price proxies for the marginal utility of income, with WTP for product (non-price) attribute *m* given by:

$$(4)\ \ WTP_m = -\frac{\beta_m}{\beta_p}$$

Of particular interest is the impact of gene drive insect presence on the marginal WTP for the certified organic attribute. As long as both are not treated as random coefficients, to calculate the percent change in mWTP we can simply examine the ratio of the attribute coefficient estimates for organic with $\beta_{Org|\widehat{(GD_{Ins}}=1)}$ and without $\beta_{Org|\widehat{(GD_{Ins}}=0)}$ the presence of

[3] Interaction terms modeled as fixed due to consistent insignificance of standard deviation estimates in mixed logit models (full results available upon request).
[4] Results presented are robust to bootstrapping and available upon request.

gene drives, given by: $\frac{\beta_{Org|(\widehat{GD}_{Ins}=1)} - \beta_{Org|(\widehat{GD}_{Ins}=0)}}{\beta_{Org|(\widehat{GD}_{Ins}=0)}}$. This can translate directly to changes in WTP due to the fact that the price coefficient, as well as any underlying scale factor, will both cancel.

DCE Estimation Results

Choice Frequencies

Through a very basic lens, in Figure 1 we can glean initial insights from examining the choice frequencies when each key attribute levels are present. As the final experimental design is no longer orthogonal since we update beta priors with pre-test results, choice frequencies presented are normalized by price level. We find largely similar selection patterns between fresh blueberries and orange juice, with gene drive insect alternatives selected at the same rate or significantly more frequently than either GM plant modification or high-level conventional insecticide spraying.

We begin by grounding ourselves in the choice frequency of a generally regarded 'good' attributes. At the lowest price level, an organic option in the blueberry or orange juice choice set was selected 73% and 76% of the time, respectively. High frequency of pesticide sprays, which is quite common with the establishment of Spotted Wing and Asian Citrus Psyllid, decreases choice frequency to 47-48%. While conventional products do not generally note the level of field spraying on product labels and therefore consumers may or may not be aware of spraying intensity, this choice nevertheless illustrates the preferences held. An insect-resistant GM blueberry plant is selected slightly less frequently, at 43.5% (p=0.093, two-sample t-test), statically equal to a GM orange tree (49.8%; p=0.299). Compared to high-frequency spraying, alternatives with gene drive insects are selected equivalently in fresh blueberries (50.2%; p=0.387) or chosen more frequently for orange juice (60.6%; p<0.001). Alternatives without GM plants or drive insects are chosen more frequently than with drive insects alone in both products (BB: p<0.001; OJ: p=0.089). At the highest price level, alternatives with drive insects are chosen more than high spray levels in both blueberries (21.8% v. 12.3%; p<0.001) and orange juice (21.0% v. 15.4%; p=0.021).

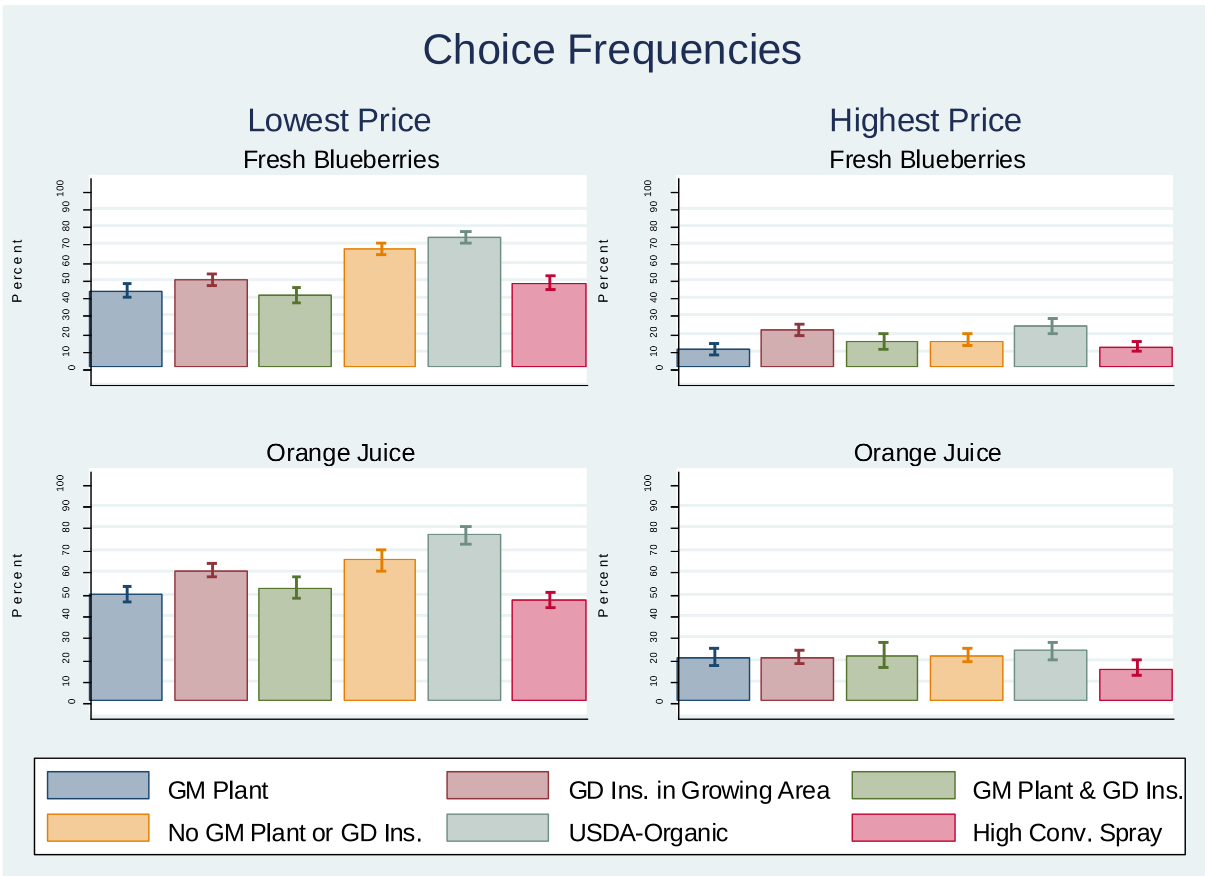

Figure 1: Percentage Respondents Selecting when Attribute Levels Present

Model Estimation

Fresh Blueberries

Conditional Logit Results

Model estimation begins with a preliminary conditional logit model in utility space (Table 5, col. 1&2) which assumes homogeneous preferences across consumers. Fresh blueberry consumers negatively value genetic modifications to the plant itself and gene drive insect presence. However, the mean disutility for gene drive insect presence is less than half that induced by a genetically modified blueberry plant, which is important as future biotechnology alternatives are considered. Consumers prefer both low spray and certified organic pest management practices to a high conventional pesticide spraying regime, which is representative of current conventional practices. We can also interpret the negative of the low (v. high) spray coefficient as the

In this model, gene drive insects appears to impact the marginal utility of pest management regimes, decreasing the marginal value of more environmentally friendly methods. In particular, there is a modest but statistically significant 23.9% ($p<0.001$)[5] reduction in marginal utility for certified organic status, a ratio which directly translates to a percentage decline in willingness-to-pay. This result would indicate a decline in the value denoted by the certification, though this result softens as we relax IIA in the mixed logit model.

Mixed Logit Results

A mixed logit model (Table 5, col. 3&4), accounting for unobserved heterogeneity, provides marked improvements in model likelihood. The relative impact of biotechnology strategies for

[5] Standard error calculated via Delta Method (using *nlcom* command in *Stata*)

pest mitigation remains roughly unchanged – the mean effect of genetically engineering the plant is nearly twice that of gene drive insects, resulting in a mean $1.07/pint reduction in WTP for a GM plant and $0.55/pint reduction for gene drive insect presence (Table 6). Compared to a high frequency conventional spraying regime, there is a mean $1.82/pint premium for certified organic management and a $0.63/pint premium for low frequency conventional spraying. In the model with attribute interactions and independent coefficients, the heterogeneity in gene drive insect impact remains across pest management regimes, though the difference is now only significant for certified organic production (column 4). While the organic premium in the absence of drive insects is $1.91/pint, this decreases by a modest by statistically significant 22.5% ($0.43/pint) when drive insects are present.

As we allow all non-price random main effects to be correlated (T5, col. 5&6), we see important shifts in results which we are still exploring. The disutility from a GM plant continues to be about twice that of drive insect presence. Further, the disutility from a high spray conventional regime, computed by the negative of the low spray coefficient, remains greater than drive insect presence in the main effects model (col. 5). Regarding impacting on organic valuation, the interaction coefficient with gene drive insects is attenuated and much noisier in the fully correlated model, with an implied insignificant 6.8% reduction in organic WTP (Table 6). The sensitivity of the results to this fully correlated specification – which has much higher explanatory power –merits further exploration to determine appropriate policy recommendations.

Table 5: Fresh Blueberries - Preference Space Estimates

VARIABLES	(1) Cond. Logit Base Coeff. (s.e.)	(2) Cond. Logit Full Coeff. (s.e.)	(3) MXL Uncorrelated Base Coeff. (s.e.)	(4) MXL Uncorrelated Full Coeff. (s.e.)	(5) MXL Correlated Base Coeff. (s.e.)	(6) MXL Correlated Full Coeff. (s.e.)
Mean						
Price	-0.531***	-0.521***	-0.843***	-0.850***	-0.883***	-0.897***
	(0.0245)	(0.0250)	(0.0291)	(0.0319)	(0.034)	(0.036)
Plant GM	-0.377***	-0.376***	-0.898***	-0.913***	-1.056***	-1.152***
	(0.0692)	(0.0693)	(0.106)	(0.106)	(0.125)	(0.132)
GD Insects	-0.160***	0.000229	-0.467***	-0.271**	-0.612***	-0.568***
	(0.0492)	(0.0700)	(0.0750)	(0.116)	(0.094)	(0.137)
Organic (v. High Spray)	0.848***	0.950***	1.536***	1.626***	1.809***	1.934***
	(0.0833)	(0.0972)	(0.125)	(0.150)	(0.172)	(0.186)
GD insects x Org.		-0.227***		-0.369***		-0.132
		(0.0831)		(0.143)		(0.156)
Low Spray (v. High)	0.200***	0.320***	0.527***	0.654***	0.701***	0.776***
	(0.0720)	(0.0791)	(0.0972)	(0.119)	(0.143)	(0.149)
GD insects x Low Spray		-0.257***		-0.245		-0.092
		(0.0976)		(0.168)		(0.174)
Opt-out	-1.807***	-1.698***	-3.471***	-3.340***	-3.499***	-3.523***
	(0.124)	(0.130)	(0.177)	(0.182)	(0.240)	(0.231)
SD[1]						
Plant GM			1.395***	1.455***	1.969***	2.000***
			(0.124)	(0.127)	(0.156)	(0.157)
GD Insects			0.870***	1.014***	0.593***	0.390***
			(0.124)	(0.110)	(0.130)	(0.097)
Organic			1.769***	1.896***	2.365***	1.128***
			(0.138)	(0.143)	(0.241)	(0.249)
Low Spray			-0.886***	1.166***	-0.349***	0.494***
			(0.146)	(0.146)	(0.382)	(0.208)
Opt-out			2.553***	2.470***	1.997***	1.729***
			(0.155)	(0.152)	(0.321)	(0.252)
Observations	12,339	12,339	12,339	12,339	12,339	12,339
LL	-3898	-3895	-3229	-3220	-3073	-3068

Note: Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$. [1]For full covariance matrix of col. 5&6 models with correlated random coefficients, see appendix (omitted here for space).

Table 6: Fresh Blueberries – WTP Estimates

VARIABLES	(1) Cond. Logit - Base	(2) Cond. Logit – Full	(3) MXL Uncorrelated Base	(4) MXL Uncorrelated Full	(5) MXL Correlated Base	(6) MXL Correlated Full
Plant GM	-0.709*	-0.722*	-1.065*	-1.074*	-1.196*	-1.285*
	[-0.971, -0.447]	[-0.990, -0.454]	[-1.305, -0.826]	[-1.314, -0.835]	[-1.471, -0.921]	[-1.571, -0.999]
GD Insects	-0.302*	0.0004	-0.554*	-0.319*	-0.693*	-0.634*
	[-0.488, -0.116]	[-0.263, 0.264]	[-0.724, -0.383]	[-0.582, -0.056]	[-0.900, -0.487]	[-0.922, -0.345]
Org. (v. High Spr.)	1.595*	1.823*	1.822*	1.914*	2.050*	2.157*
	[1.250, 1.941]	[1.412, 2.234]	[1.542, 2.102]	[1.575, 2.252]	[1.662, 2.436]	[1.754, 2.560]
GD Insects x Org.		-0.436*		-0.434*		-0.148
		[-0.756, -0.115]		[-0.765, -0.103]		[-0.489, 0.194]
Low Spr. (v. High)	0.377*	0.614*	0.625*	0.769*	0.794*	0.865*
	[0.108, 0.647]	[0.304, 0.924]	[0.405, 0.846]	[0.492, 1.047]	[0.473, 1.116]	[0.531, 1.198]
GD insects x Low Spray		-0.494*		-0.288		-0.103
		[-0.874, -0.114]		[-0.682, 0.105]		[-0.486, 0.281]
Opt-out	-3.401*	-3.260*	-4.117*	-3.931*	-3.963*	-3.929*
	[-3.707, -3.094]	[-3.589, -2.931]	[-4.454, -3.779]	[-4.255, -3.607]	[-4.398, -3.528]	[-4.340, -3.518]

Note: 95% confidence intervals constructed by Delta method (Hole 2007)

Orange Juice

Conditional Logit Results

When assuming homogeneous preferences among orange juice consumers, disutility derived from gene drive insect presence is statistically equivalent to that of a genetically modified orange tree (Table 7, col. 1; p=0.973). Each biotechnology strategy is associated with a mean $0.55/half-gallon reduction in WTP (Table 8). Compared to a high frequency conventional spray regime, there is a $1.49/half-gallon premium for certified organic production and a $0.92/half-gallon premium for a low frequency spray regime. The presence of gene drive insects decreases marginal utility (and WTP) for organic certification by a statistically significant 20.28% (p=0.014).

Mixed Logit Results

However, when incorporating heterogeneity across respondent preferences, the mean reduction in WTP for a GM orange tree is nearly 47% greater than the reduction for gene drive insect presence. While meaningful, this difference between biotechnology strategies remains lower than that found for blueberry production. Mean reduction in WTP from gene drive insects, as well as premiums for organic production and low spray regimes are relatively unchanged in the mixed logit specification and allowing random main effects to be correlated does not qualitatively change results.

For both mixed logit models, the magnitude of the relative reduction in WTP for organic pest management when drive insects are present is on the order of 10-11%, but this estimate is not statistically significant. Modeling heterogeneity across respondents continues to be key to understanding policy-relevant impacts of these new technologies.

Table 7: Orange Juice – Preference Space Estimates

VARIABLES	(1) Cond. Logit Base Coeff. (s.e.)	(2) Cond. Logit Full Coeff. (s.e.)	(3) MXL Uncorrelated Base Coeff. (s.e.)	(4) MXL Uncorrelated Full Coeff. (s.e.)	(5) MXL Correlated Base Coeff. (s.e.)	(6) MXL Correlated Full Coeff. (s.e.)
Mean						
Price	-0.605***	-0.607***	-1.023***	-1.026***	-1.078***	-1.086***
	(0.0313)	(0.0312)	(0.0399)	(0.0401)	(0.044)	(0.045)
Plant GM	-0.336***	-0.336***	-0.867***	-0.870***	-0.944***	-1.069***
	(0.0710)	(0.0702)	(0.117)	(0.117)	(0.136)	(0.146)
GD Insects	-0.333***	-0.252***	-0.590***	-0.477***	-0.628***	-0.473***
	(0.0547)	(0.0633)	(0.0788)	(0.124)	(0.094)	(0.144)
Organic (v. High Spray)	0.904***	1.006***	1.555***	1.640***	1.674***	1.811***
	(0.0908)	(0.101)	(0.133)	(0.160)	(0.180)	(0.210)
GD insects x Org.		-0.204**		-0.170		-0.204
		(0.0905)		(0.176)		(0.195)
Low Spray (v. High)	0.558***	0.569***	0.980***	1.036***	1.200***	1.345***
	(0.0680)	(0.0895)	(0.0893)	(0.109)	(0.122)	(0.143)
GD insects x Low Spray		-0.0515		-0.151		-0.259
		(0.0898)		(0.147)		(0.158)
Opt-out	-2.804***	-2.785***	-5.421***	-5.396***	-5.515***	-5.561***
	(0.175)	(0.179)	(0.252)	(0.253)	(0.290)	(0.300)
SD[1]						
Plant GM			1.774***	1.765***	4.401***	4.735***
			(0.133)	(0.133)	(0.661)	(0.743)
GD Insects			0.723***	0.729***	1.431***	1.310***
			(0.122)	(0.123)	(0.285)	(0.270)
Organic			1.763***	1.755***	8.045***	8.497***
			(0.158)	(0.159)	(1.073)	(1.126)
Low Spray			0.945***	0.940***	2.568***	2.614***
			(0.124)	(0.124)	(0.487)	(0.465)
Opt-out			2.722***	2.724***	11.503***	12.025***
			(0.183)	(0.183)	(1.400)	(1.480)
Observations	11,016	11,016	11,016	11,016	11,016	11,016
LL	-3668	-3667	-2996	-2995	-2856	-2862

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. [1]For full covariance matrix of col. 5&6 models with correlated random coefficients, see appendix (omitted here for space).

Table 8: Orange Juice - WTP Estimates

VARIABLES	(1) Cond. Logit - Base	(2) Cond. Logit – Full	(3) MXL Uncorrelated Base	(4) MXL Uncorrelated Full	(5) MXL Correlated Base	(6) MXL Correlated Full
Plant GM	-0.555*	-0.554*	-0.847*	-0.847*	-0.876*	-0.985*
	[-0.788, -0.322]	[-0.784, -0.324]	[-1.065, -0.630]	[-1.063, -0.631]	[-1.118, -0.634]	[-1.238, -0.732]
GD Insects	-0.550*	-0.416*	-0.577*	-0.465*	-0.583*	-0.435*
	[-0.738, -0.362]	[-0.625, -0.208]	[-0.730, -0.423]	[-0.703, -0.226]	[-0.757, -0.409]	[-0.697, -0.173]
Org. (v. High Spray)	1.494*	1.659*	1.520*	1.598*	1.553*	1.668*
	[1.177, 1.813]	[1.310, 2.008]	[1.283, 1.756]	[1.306, 1.889]	[1.237, 1.869]	[1.301, 2.035]
GD Insects x Org.		-0.336*		-0.165		-0.188
		[-0.629, -0.044]		[-0.501, 0.170]		[-0.540, 0.164]
Low Spray (v. High)	0.923*	0.937*	0.957*	1.009*	1.113*	1.239*
	[0.685, 1.162]	[0.629, 1.245]	[0.792, 1.122]	[0.812, 1.207]	[0.891, 1.335]	[0.984, 1.494]
GD insects x Low		-0.085		-0.147		-0.238
Spray		[-0.376, 0.206]		[-0.427, 0.133]		[-0.522, 0.045]
Opt-out	-4.638*	-4.591*	-5.297*	-5.258*	-5.116*	-5.121*
	[-4.942, -4.334]	[-4.907, -4.276]	[-5.617, -4.977]	[-5.583, -4.932]	[-5.471, -4.761]	[-5.492, -4.749]

Note: 95% confidence intervals constructed by Delta method (Hole 2007)

Main Effects Summary: Comparing Biotechnology and Heavy Chemical Control

In Figure 2, we present a summary of main effect WTP results using estimates from the fully correlated mixed logit specifications for each product DCE. Biotechnology interventions are not viewed as equivalent by consumers. For both products, genetically modifying the plant for insect resistance has a much greater negative effect on WTP (BB: p<0.001; OJ: p=0.018). For blueberries, there is no statistically significant difference between increasing from a low to high conventional spray regime and gene drive insect presence (p=0.548). In orange juice, however, drive insects have a much lower impact on WTP (p=0.001). Therefore, when evaluating strategies to combat damaging invasive species, a consistent and robust finding is that drive insects have a lower impact on mean consumer WTP for conventionally produced food products compared to alternative biotechnology approaches and heavily increased insecticide spraying.

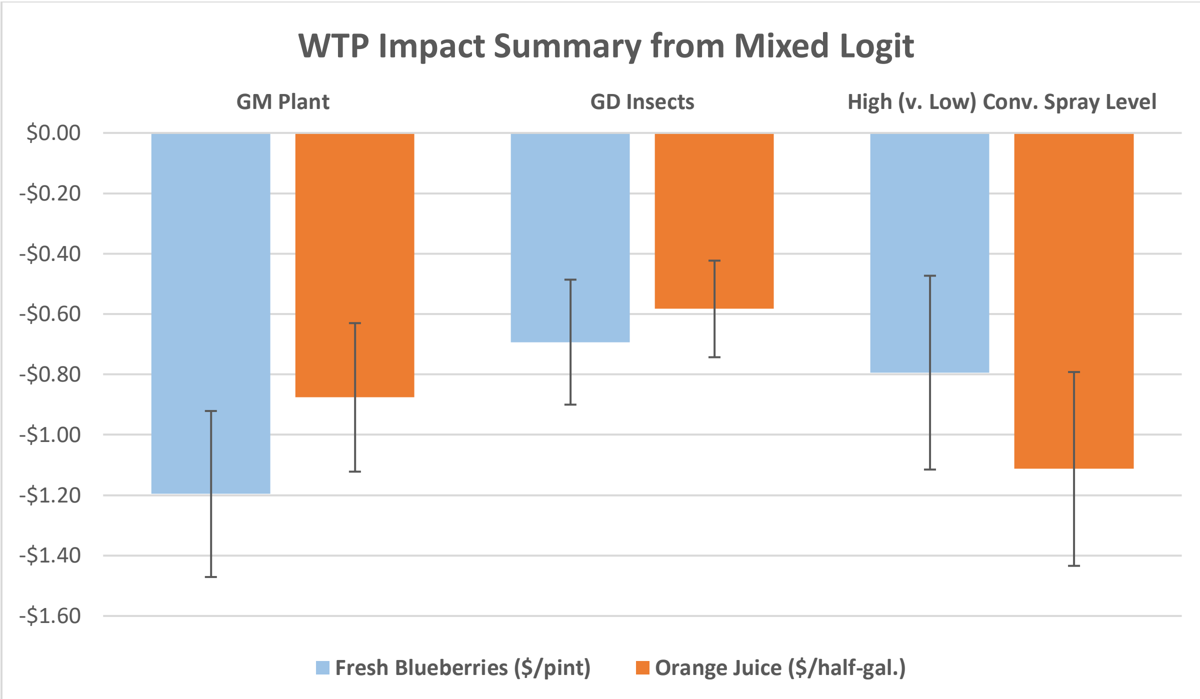

Figure 2: Comparing WTP Effects of Escalated Pest Management Strategies
Note: Mixed Logit Model with correlated random main effects (Col. 5 of Table 7 & 8). Comparisons of coefficients in this graph should only be made for attributes of the same product.

Heterogeneity Analysis: A Deeper Focus on Organics

As a gene drive approach could decrease pest and disease pressure without the need for pesticide applications, this could provide benefits to organic production systems. However, decisions to purchase certified organic products are inherently linked to the value the seal provides in communicating the presence or lack of key search attributes. Those purchasing certified organic products to specifically avoid genetically modified foods may or may not find the introduction of gene drive insects to be an acceptable way to reduce pest pressure and subsequent pesticide use. In this section, we delve deeper into attitudinal reporting and how these stated attitudes are reflected by trade-offs estimated in the DCE. Just over 22% of respondents (n=228) self-identified as ‘regularly’ purchasing certified organic food products. Among these regular purchasers, 53.5% indicated purchasing organics is influenced by a desire to avoid genetically modified foods. This may translate into general desire to avoid all genetically modified organisms, whether modified crops or modified insects in the environment.

We directly ask respondents to rate their support for USDA-Organic certification retention in the presence of gene drive insects. Among those affirming ‘regular’ purchase of certified organic products (n=228), 28% believe that farmers should *not* retain USDA-organic certification when drive insects are present “in the growing area”, slightly less than half (43%) believe farmers *should* retain certification, and a non-trivial 29% are neutral. When gene drive insect material is “in or on crops”[6], almost 39% believe farmers should *not* retain certification – just ahead of the 35% who believe they *should* retain certification. About 26% are neutral.

The extent to which gene drive insect presence impacts the quantifiable valuation of organic certification is an area of key policy relevance, and attitudinal results imply potential economically meaningful effects for some sub-groups which may potentially be washed out by only examining mean effects. The presentation of gene drive insects ‘in the area’ to control a damage species was the attribute level presented to respondents in the DCE. It is not known

[6] **Organic Certification Question, part 1 [accompanied by USDA-Organic seal for visual cue]:** “Currently, for a food product to be certified 'USDA-Organic’, the United States Department of Agriculture has strict regulations on what types of pesticides may be used and does not allow the use of genetically modified crops. Suppose a farmer is following all current requirements for certified organic production and ‘gene drive’ insects are used in the area to control a damaging insect species. To what extent do you agree or disagree that this farmer's crops should still be allowed to be certified as 'USDA-Organic'?”
Organic Certification Question, part 2 [accompanied by USDA-Organic seal for visual cue]: “Now, suppose a farmer is still following all requirements for certified 'USDA-Organic' production, and the use of gene drive insects in the area results in some genetically modified insect eggs, immature larva, or adults getting on or in the crops. To what extent do you agree or disagree that this farmer’s crops should still be allowed to be certified as 'USDA-Organic’?”

how DCE results may change if it was explicitly stated that insect material was on the product to be purchased, but attitudinal results suggest there may be a stronger market reaction. However, as respondents completed the DCE *after* reporting attitudes on certification, we made them aware as possible of the levels of potential interaction with crops.

'Regular' Organic Buyers

Given calls from gene drive funders and sponsors 'ensure the perspectives of those most affected are taken into account' (Emerson et al., 2017; p.1136), we probe the sub-population of frequent organic consumers as they may have particular concerns. Fully interacting self-identification as a 'regular' buyer of certified organic food products, we gain more insight into differential impacts across both fresh blueberries and orange juice in Table 79. Within the samples completing the fresh blueberry and orange juice DCEs, 28.4% and 19.7%, respectively, identify as regular organic buyers.

As expected, for both fresh blueberries and orange juice, organic certification is much more highly valued among regular organic buyers than the remaining population.

For fresh blueberries (Table 9), those *not* regularly buying organics still have an economically significant 26.1% decline in valuation for certification with drive insect presence. While regular buyers have nearly three times the valuation of organic certification, there is no significantly higher reduction caused by drive insects. Thus, while the absolute reduction in valuation is slightly (and insignificantly) higher, the net *percent* reduction in organic valuation is *lower* among regular buyers, with a mean net 11.9% decline.

In orange juice (Table 7; col. 2), those not buying organics regularly have no statistically significant reduction in WTP for organic certification when gene drive insects are present. However, regular organic buyers not only have higher organic valuation, but also a significantly higher reduction in organic valuation in the presence of gene drive insects – for a net 24.3% decline.

Table 9: Heterogeneity Analysis –Splitting by 'regular' organic buyers – Fresh Blueberries

VARIABLES	(1) MXL Uncorrelated		(2) MXL Correlated	
	Mean	SD[1]	Mean	SD
Price	-0.874***			
	(0.0325)			
Base: Does not identify as a 'regular' organic buyer of food products				
Plant GM	-0.667***	1.311***		
	(0.116)	(0.130)		
GD Insects	-0.109	0.561***		
	(0.122)	(0.143)		
Org. (v. High Spray)	1.083***	1.474***		
	(0.158)	(0.130)		
GD Insects x Org.	-0.283*			
	(0.163)			
Low Spray (v. High)	0.612***	-0.897***		
	(0.132)	(0.168)		
GD insects x Low Spray	-0.329*			
	(0.186)			
Opt-out	-3.904***	2.604***		
	(0.225)	(0.150)		
Interacting with Regular Organic Buyer Status				
Plant GM x Reg. Org. Buyer	-0.906***	1.086***		
	(0.246)	(0.275)		
GD Insects x Reg. Org. Buyer	-0.872***	1.328***		
	(0.278)	(0.229)		
Org. (v. High Spray) x Reg. Org. Buyer	2.291***	1.836***		
	(0.327)	(0.306)		
GD Insects x Org. x Reg. Org. Buyer	-0.119			
	(0.340)			
Low Spray (v. High) x Reg. Org. Buyer	0.393	1.340***		
	(0.281)	(0.267)		
GD insects x Low Spray x Reg. Org. Buyer	0.901**			
	(0.374)			
Opt-out x Reg. Org. Buyer	1.251***	0.984***		
	(0.315)	(0.340)		
Observations	12,339		12,339	
% 'Regular' organic buyers	28.4%		28.4%	
LL	-3127		-2791	

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. [1]For full covariance matrix of col. 2 model with correlated random coefficients, see appendix (omitted here for space).

OJ: Average decline in organic WTP with gene drive insect presence – 26.1%.

Table 10: Heterogeneity Analysis –Splitting by 'regular' organic buyers – Orange Juice

VARIABLES	(1) MXL Uncorrelated Mean	(1) MXL Uncorrelated SD	(2) MXL Correlated Mean	(2) MXL Correlated SD
Price	-1.039***		-1.151***	
	(0.0411)		(0.049)	
Base: Does not identify as a 'regular' organic buyer of food products				
Plant GM	-0.771***	1.677***	-0.856***	
	(0.128)	(0.142)	(0.158)	
GD Insects	-0.566***	0.588***	-0.619***	
	(0.133)	(0.147)	(0.168)	
Org. (v. High Spray)	1.276***	1.597***	1.662***	
	(0.171)	(0.158)	(0.246)	
GD Insects x Org.	0.00223		0.026	
	(0.193)		(0.226)	
Low Spray (v. High)	0.924***	0.828***	1.367***	
	(0.116)	(0.128)	(0.178)	
GD insects x Low Spray	-0.0129		-0.075	
	(0.161)		(0.181)	
Opt-out	-5.410***	2.569***	-5.567***	
	(0.264)	(0.165)	(0.328)	
Interacting with Regular Organic Buyer Status				
Plant GM x Reg. Org. Buyer	-0.639*	2.304***	-0.991**	
	(0.339)	(0.510)	(0.403)	
GD Insects x Reg. Org. Buyer	0.552	-1.345***	0.512	
	(0.411)	(0.340)	(0.491)	
Org. (v. High Spray) x Reg. Org. Buyer	2.820***	2.014***	3.794***	
	(0.488)	(0.332)	(0.654)	
GD Insects x Org. x Reg. Org. Buyer	-0.996*		-1.451**	
	(0.508)		(0.612)	
Low Spray (v. High) x Reg. Org. Buyer	0.586*	-1.278***	1.370***	
	(0.311)	(0.263)	(0.498)	
GD insects x Low Spray x Reg. Org. Buyer	-0.870**		-1.125**	
	(0.418)		(0.519)	
Opt-out x Reg. Org. Buyer	0.374	0.950***	0.574	
	(0.358)	(0.246)	(0.603)	
Observations	11,016		11,016	
% 'Regular' organic buyers	19.7%		19.7%	
LL	-2958		-2791	

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. [1]For full covariance matrix of col. 2 model with correlated random coefficients, see appendix (omitted here for space).

Conclusions and Policy Recommendations

Increasingly successful scientific research is developing the use of gene drive insects to combat invasive agricultural pests which cause significant damage in U.S. growing environments. Researchers, funders, and policy makers have already begun a broad debate on the ethics and potential ecological impacts of such technologies (NASEM 2016; Emerson et al., 2017; Baltzegar et al., 2018), and market impacts will also be a key concern to address in deliberations over potential releases. The net market impacts of these technologies depend not only on the cost savings and yield improvement afforded to producers, but also how consumers will react in the marketplace.

We evaluate consumer preferences for multiple strategies to address damaging invasive pests, including gene drive insects, crop genetic modification, and heavy conventional pesticide spraying regimes. Unsurprisingly, results indicate that consumers prefer less insecticide and no use of biotechnology. However, the introduction of Spotted Wing Drosophila as a major invasive pest has already led to increased spraying and control costs. Similarly, the threat of citrus greening spread has spurred heavy spray programs to attempt to control Asian Citrus Psyllid. More pesticides are already a reality in these growing environments. Our results consistently indicate, across both fresh blueberries and orange juice experiments, that consumers had lower or statistically equivalent reductions in mean WTP with gene drive insect presence in growing areas compared to current high spray regimes. On average, gene drive insects are also consistently preferred to control via crop genetic modification, providing insight into differential public and consumer perceptions of biotechnology interventions. It is logical that GMO organism presence in the field would elicit a weaker consumer reaction than a genetically engineered product which is directly (and intentionally) consumed. This may attenuate some concern about major impacts on general demand for host crop food products – if releases allow spray levels are to be reduced back to previous levels.

We also examine potential impacts on WTP for organic certification. While organic producers may in fact receive very high production benefits from gene drive insects to reduce damage without chemical applications, it is reasonable to expect that some segments of their consumer base may be hesitant to accept this new technology. Among organic consumers, attitudinal data do suggest meaningful stated opposition to grower certification when genetically modified insect material is in or on crops, although a roughly similar proportion indicate support. Opposition declines as the proximity of insects to crops increases, with a much greater proportion (but non-majority) supporting certification when drive insects are simply in the growing area. However, for the full sample, there is weaker evidence for mean WTP declines for organic products when drive insects are in growing areas. While this interactive effect initially appears modest but economically meaningful in heavily assumptive models, the effect dissipates and is not statistically significant for either product in more sophisticated mixed logit specifications. Heterogeneity in buying patterns improves understanding of how drive insects may impact niche groups in the marketplace. Among consumers who do not regularly purchase organic products, there is no significant impact on WTP for organic certification. However, among the roughly 20% of consumers indicating 'regular' organic purchases, gene drive insects reduce WTP for organic certification by about 25% in orange juice and about X% in fresh blueberries. Caution and continued engagement with this sub-group of heavy organic purchasers is merited to clarify fundamental drivers of this effect as they likely represent a much larger relative volume of organic consumption.

There are some drawbacks to this study. Awareness of pest control measures will be important in extrapolating these results. Our experiment clearly labeled product features, though perfect information may not be available to many consumers in the marketplace. Further, while increased pesticide application may not be heavily publicized, impending trial releases of non-drive GM mosquitoes in Florida led to heavy media coverage (see: Allen, 2016; Servick, 2016). Gene drive insect releases may be similarly publicized, which could increase awareness and potentially lead to a greater overall market impact.

Further research is needed to connect underlying values driving differential impacts of plant and insect-based biotechnology solutions. While our information frame was delivered as objectively as possible, the public may hear about gene drive insects through outlets which are encouraging either support or opposition. Investigating informational and framing effects on subsequent consumer decision-making would help to understand implications for consumption. Finally, this work needs to extend to an analysis of welfare impacts of removing alternatives from the choice sets, as well combine producer data with consumer surplus estimates to provide insight into market-wide net impacts.

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Appendix A.

Choice scenario example: Fresh Blueberries

	**Option A**	**Option B**	**Option C**
Pest Control	Conventional insecticides applied every five days when fruit is ripe	USDA ORGANIC	I would not purchase either one of these products
Plant Type	The plant is not genetically modified	The plant is not genetically modified	
Gene Drive Insects	Gene drive insects were present in the area to control pest damage	Gene drive insects were present in the area to control pest damage	
Price	$1.06/pint	$2.12/pint	

Choice scenario example: Orange Juice

 	**Option A**	**Option B**	**Option C**
Insecticide Use	Conventional insecticides applied in the field 1-2 times per year	USDA ORGANIC	I would not purchase either one of these products
Plant Type	The plant and fruit are not genetically modified	The plant and fruit are not genetically modified	
Gene Drive Insects	No gene drive insects were present in the growing area	Gene drive insects were present in the area to control pest damage	
Price	$4.07/half-gallon	$5.21/half-gallon	

Appendix B.

Full introductory information and FAQ items

The survey informational text is in quotations (emphasis in text present in fielded survey). Invisible timers recorded time spent on each page.

Introduction with consequentiality statement:

"You will be shown four (4) short pages in the next section. Please read the information carefully.

Your responses to questions about this information will inform policy decisions at the U.S. Department of Agriculture."

Panel 1:

"*(Page 1 of 4)*

In this section, we are going to ask your opinion about a new technology being developed. We will first give a bit more detail about the technology and then two examples of how people are proposing to apply it in food production. We will also ask how use of this technology may affect your food purchases.

Insect pests cause significant damage to crops in the United States. Farmers try to control these insects as scientists continue to develop new pest control methods and technologies.

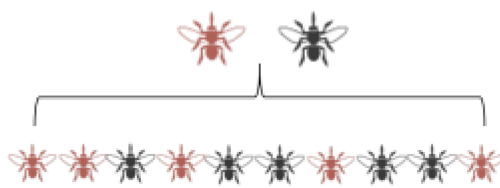
As you may have heard, a new strategy under development is called a 'gene drive', using a genetic engineering technology called CRISPR/CAS9 (pronounced "crisp-er"). **With this approach, scientists may be able to modify the genes of insect pests 1) to prevent them from being able to transmit diseases to a crop or 2) to reduce their populations by preventing them from reproducing normally."**

Panel 2:

“(Page 2 of 4)

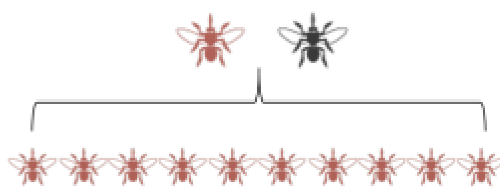
How does a gene drive work?

Imagine you wanted to make a population of insects a different color. Normally, half of an offspring’s genes come from the father and half come from the mother. So if a male with some genetic change mated with a normal female, about half of the offspring would inherit the change in the father’s DNA. **This is illustrated in the figure below.**



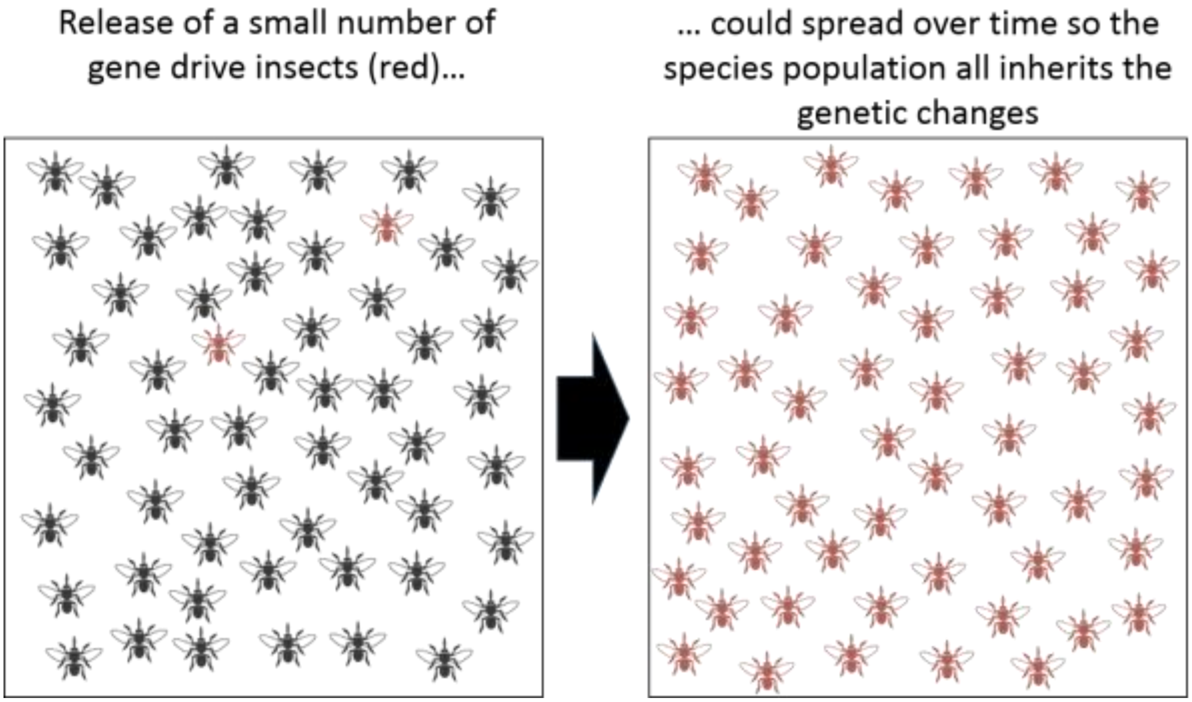
Normal Inheritance
(red insects have a new genetic change)

However, with a ‘gene drive’, genetic changes are inherited by almost 100% of the offspring. Their offspring then pass on these genetic changes to the next generation, continuing the process. **This is represented in the figure below.**



Increased Inheritance with Gene Drive
(red insects have a new genetic change)

This means, in theory, if you release gene drive insects, over time they could 'drive' the modified genes to the entire population of that insect species (demonstrated below). These changes could potentially spread to wherever that insect occurs in the world.



In agriculture, some scientists have proposed spreading modified genes which could prevent insects from transmitting crop diseases. Other scientists have also proposed spreading genes to disrupt insect reproduction to reduce or eliminate local populations of specific insect pests.

However, gene drives have never been used in the environment, and there could be many reasons why they could fail to spread as intended."

Panel 3:

“(Page 3 of 4)

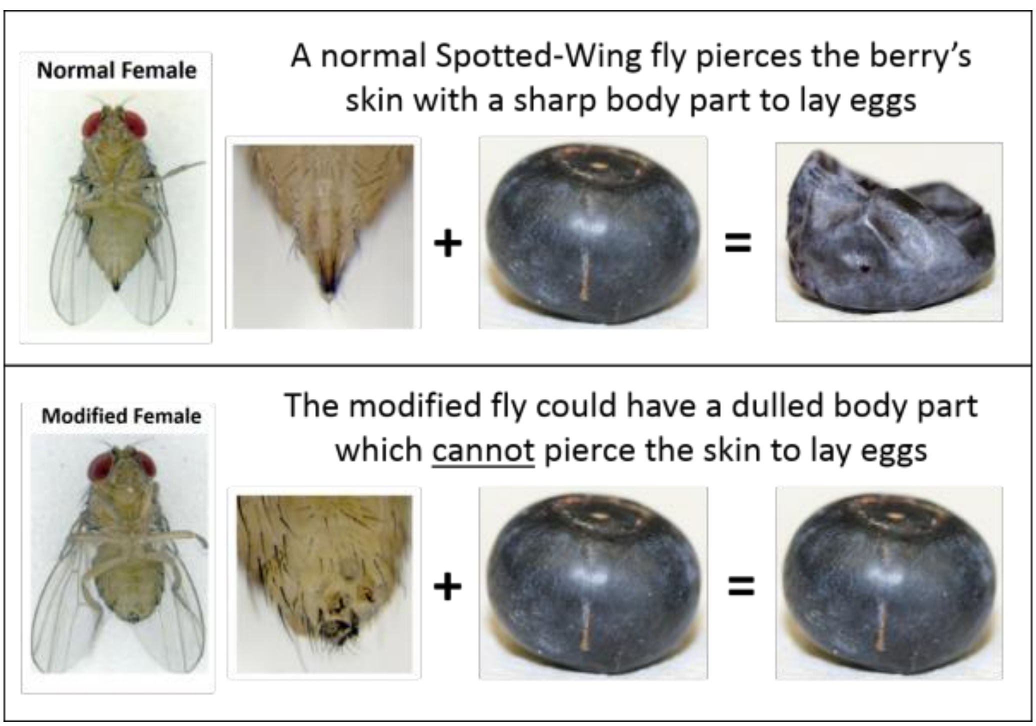
Gene drives could potentially be used to reduce or eliminate an insect population

An example under consideration is an invasive species of fruit fly called ‘Spotted-Wing Drosophila’, which recently arrived from East Asia. This pest causes significant damage to crops, especially soft berries like blueberries, raspberries, and strawberries (see picture below). The fly lays eggs inside the berries, which develop into juvenile insects that eat the fruit. Contaminated shipments cannot be sold as fresh fruit.

To prevent damage from Spotted-Wing, many farmers have increased insecticide applications, spraying up to every 3-5 days and frequently approaching limits enforced by the U.S. Environmental Protection Agency. Organic farmers have fewer insecticide options than non-organic farmers for this pest, meaning they often have higher losses. Many farms have also stopped growing fruit or have gone out of business because they could not afford to control this pest.

Scientists have proposed genetically modifying the insects to make female Spotted-Wing flies not able to lay eggs inside the fruit (see picture below). Males would be modified to pass on genes which cause their female offspring to not be able to lay eggs. The male offspring would survive, mate with normal (wild) females, and continue the process.

This could eventually reduce or locally eliminate this fruit fly. A reduction in flies could mean less damage and a reduced need for insecticide sprays to protect certain fruit crops.



Base photo credits: Berries: Vaughn Walton, Oregon State University; Flies: Li and Scott (2016), NC State University.

Panel 4:

"*(Page 4 of 4)*

Gene drives could potentially be used to alter a population of insects to not transmit crop diseases

One example is the invasive species Asian Citrus Psyllid (pronounced "si-lid") which recently arrived from East Asia. This pest spreads a type of bacteria which causes a very damaging disease called "citrus greening" in U.S. citrus groves.

Citrus greening is not harmful to humans and the fruit is still safe for people to consume. However, citrus greening causes trees to slowly die and significantly reduces the amount of fruit produced (see picture below). To slow the spread of the disease, many farmers have increased insecticide spraying up to 11-14 applications per year, frequently approaching limits enforced by the U.S. Environmental Protection Agency. Citrus greening has cost the U.S. citrus industry billions of dollars because infected trees cannot be cured of the disease and increased insecticide spraying has not successfully controlled the insect. Many farms have stopped growing citrus or have gone out of business.

Example of healthy vs. citrus greening fruit and leaves from a healthy vs. citrus greening tree
Photo credit: University of Florida

Scientists have proposed genetically modifying the Asian Citrus Psyllid so it cannot transmit the bacteria that causes citrus greening disease. The insects would continue to live and reproduce in the citrus groves, but they would no longer pass the disease to trees. The gene drive could potentially spread this disease immunity to the entire species around the world."

FAQs were presented in a 'select all' format, with presentation order randomized to avoid order effects. Unselected FAQs were presented to respondents with p=1/3. An understanding of some respondents' likely remaining uncertainties was gained from focus group discussions and survey instrument pretesting via Amazon Mechanical Turk (n=300, restricted to U.S. adults). Significant overlap with FAQs generated for press/public release by the Wyss Institute at Harvard led to significant drawing of material from this source (https://wyss.harvard.edu/staticfiles/newsroom/pressreleases/Gene%20drives%20FAQ%20FINAL.pdf).

FAQ introduction text:

"Frequently Asked Questions (FAQs)

During discussions with the public about gene drives in agriculture, people have frequently asked a number of questions. In reading the information on the previous pages, you may have wondered about similar things.

We have included a short series of seven FAQs with a brief explanation for each. **Please mark all questions you would like to learn more about.** You will be shown information on all questions you select. Answers to some questions may be randomly shown whether you select them or not.

- Is a gene drive insect the same as a genetically modified organism (GMO)?
- Would engineered gene drives work in any species?
- Could gene drives be created to affect human populations?
- Has anyone created an actual gene drive?
- What are some possible risks of gene drives?
- Could a genetically modified Spotted-Wing fly or Asian Citrus Psyllid bite humans?
- How long would the gene drive remain in an insect population after it's released into the environment?"

Appearing in separate frames:

FAQ 1:
"Is a gene drive insect the same as a genetically modified organism (GMO)?

Answer:
A gene drive insect is genetically modified (or 'genetically engineered'), but not all genetically modified organisms are gene drives.

The major difference is that a gene drive insect is modified with the intention that the genetic changes pass to all of their offspring and can potentially 'drive' through the population of that insect species."

FAQ 2 (adapted from Wyss Institute press release):

“Would engineered gene drives work in any species?

Answer:
No, only in species that reproduce sexually, such as insects, animals, and most plants. They would not work in bacteria or viruses, for example. The genetic changes only spread through the population as individuals mate, so it works much faster in species like insects which can reproduce very quickly.”

FAQ 3 (adapted from Wyss Institute press release):

“Could gene drives be created to affect human populations?

Answer:
Not without taking centuries. It takes a very long time to spread a gene drive through a species that takes many years to reach sexual maturity. For example, if a trait was introduced into elephants (which live for a long time, like humans) using a gene drive today, there would only be four times as many elephants with that trait in 100 years than if we hadn't used a gene drive.

No scientist has proposed using a gene drive in human beings or any higher mammal. This is partly because gene drives work best in organisms with fast reproduction cycles and many offspring (like insects).”

FAQ 4 (adapted from Wyss Institute press release):

“Has anyone created an actual gene drive?

Answer:
Yes, though work is ongoing. Some gene drive insects have been developed in specific laboratory populations by scientists, but have never been released in the wild.”

FAQ 5:

“What are some possible risks of gene drives?

Answer:
The National Academy of Science, Engineering and Medicine has stated that ‘many of the possible harmful effects of gene drives have to do with environmental outcomes’. For example, a gene drive that eliminates a species in a particular environment might have impacts on other species. Some of these impacts might be predictable, but some species serve functions in the environment that we don't yet understand very well. Even in a farmer's field, removing a pest through gene drives may leave room for another pest to fill its place. Or, if a gene drive changes the behavior of an insect pest, there might be impacts that were not predicted.

Though extremely rare, sometimes in nature genes can be transferred between species. With other genetically modified animals this has never been found, but it is not yet known if this is possible with gene drive insects."

FAQ 6:

"Could a genetically modified Spotted-Wing fly or Asian Citrus Psyllid bite humans?

Answer:
No. Neither the Asian Citrus Psyllid nor the Spotted Wing fruit fly can bite humans or other animals."

FAQ 7:
"How long would the gene drive remain in an insect population after it's released into the environment?

Answer:
Theoretically, if enough gene drive insects are released and the drive works as intended, the genetic changes could carry on indefinitely and spread throughout the entire population of that species. That said, since gene drives are still under development, it is not known for sure if specific types of gene drive insects will be successful at finding mates or if all of their offspring actually inherit the DNA changes.

Some studies have also shown that insects may be able to adapt and develop a 'resistance' to the gene drive. This process is similar to insects evolving resistance to a pesticide, with some surviving even when they are sprayed. For gene drives, this could mean the gene drive might initially spread, but break down (or stop working) after a certain period. Over time, the insect populations might return to having no genetically modified individuals."

Appendix 3: Covariance matrix for mixed logit models with correlated random effects (non-price main effects modeled as random normal)

A3a. Blueberries – Base (Table 5, Col. 5)

Fresh Blueberries - Base	GM Plant	GD Insects	Organic (v. High Spray)	Low Spray (v. High Spray)	Opt-Out
GM Plant	3.880***				
	(0.614)				
GD Insects	2.414***	1.854***			
	(0.383)	(0.334)			
Organic (v. High Spray)	1.358***	-.303	6.904***		
	(0.509)	(0.329)	(0.929)		
Low Spray (v. High Spray)	-2.319***	-.791***	2.437***	2.783***	
	(0.422)	(0.287)	(0.578)	(0.538)	
Opt-Out	-2.161***	-1.127***	3.919***	1.437**	9.426***
	(0.574)	(0.342)	(0.836)	(0.623)	(1.327)

A3b. Blueberries – Full Interactions (Table 5, Col. 6)

Fresh Blueberries - Full Interactions	GM Plant	GD Insects	Organic (v. High Spray)	Low Spray (v. High Spray)	Opt-Out
GM Plant	4.000***				
	(0.629)				
GD Insects	2.657***	1.917***			
	(0.407)	(0.352)			
Organic (v. High Spray)	-1.461***	-.118	6.591***		
	(0.436)	(0.338)	(0.851)		
Low Spray (v. High Spray)	-2.023***	-.899***	2.594***	2.889***	
	(0.402)	(0.278)	(0.518)	(0.502)	
Opt-Out	-2.340***	-1.325***	3.752***	1.813***	9.151***
	(0.558)	(0.370)	(0.667)	(0.583)	(1.207)

A3c. Orange Juice – Base (Table 7, Col. 5)

Orange Juice - Base	GM Plant	GD Insects	Organic (v. High Spray)	Low Spray (v. High Spray)	Opt-Out
GM Plant	4.401***				
	(0.660)				
GD Insects	1.620***	1.430***			
	(0.319)	(0.285)			
Organic (v. High Spray)	-2.083***	1.344***	8.044***		
	(0.508)	(0.369)	(1.072)		
Low Spray (v. High Spray)	-1.442***	.776***	4.274***	2.568***	
	(0.398)	(0.250)	(0.619)	(0.487)	
Opt-Out	-1.838***	1.090***	4.947***	3.309***	11.503***
	(0.519)	(0.356)	(0.887)	(0.656)	(1.400)

A3d. Orange Juice - Full Interactions (Table 7, Col. 6)

Orange Juice - Full Interactions	GM Plant	GD Insects	Organic (v. High Spray)	Low Spray (v. High Spray)	Opt-Out
GM Plant	4.735***				
	(0.743)				
GD Insects	1.898***	1.310***			
	(0.337)	(0.269)			
Organic (v. High Spray)	-1.871***	1.230***	8.497***		
	(0.517)	(0.377)	(1.125)		
Low Spray (v. High Spray)	-1.077***	.564	4.417***	2.613***	
	(0.390)	(0.233)	(0.630)	(0.465)	
Opt-Out	-1.586***	.953***	5.003***	3.390***	12.024***
	(0.487)	(0.339)	(0.935)	(0.664)	(1.479)

Sample Details

N=1,018 completes	% Qualified Completes
Age Categories	
- 18-29	12.48
- 30-44	24.95
- 45-59	28.39
- 60+	34.18
Sex	
- Male	52.26
- Female	47.74
Education	
- <High School	7.07
- High School	25.25
- Some College	29.08
- Bachelor	21.02
- Masters	13.75
- PhD	3.83
Household Income	
- < 25,000	11.00
- 25k to <50,000	18.37
- 50k to <75,000	15.80
- >75k	47.45
Race/Ethnicity	
- White, Non-Hisp	72.89
- Black, Non-Hisp	7.47
- Other, Non-Hisp	4.91
- Hispanic	12.38
- 2+ Races, Non-H	2.36

Additional Material:

Robustness Check: Mixed Logit - WTP Space

	Fresh Blueberries ($/pint)				Orange Juice ($/half-gallon)			
	(1)		(2)		(3)		(4)	
VARIABLES	Base		Full		Base		Full	
	Mean	Mean	Mean	SD	Mean	SD	Mean	SD
dgmpl	-1.047***	1.603***	-0.908***	1.376***	-0.889***	1.637***	-0.876***	1.634***
	(0.110)	(0.129)	(0.108)	(0.131)	(0.109)	(0.133)	(0.108)	(0.130)
dgdins	-0.517***	1.031***	-0.210*	0.704***	-0.534***	0.806***	-0.460***	0.851***
	(0.0832)	(0.139)	(0.123)	(0.242)	(0.0880)	(0.161)	(0.113)	(0.154)
dinsecto	1.569***	2.252***	1.820***	2.062***	1.384***	-1.718***	1.470***	-1.717***
	(0.137)	(0.172)	(0.157)	(0.168)	(0.119)	(0.150)	(0.147)	(0.152)
dgdinsxinso			-0.418***				-0.171	
			(0.141)				(0.167)	
dinsectcl	0.518***	1.265***	0.615***	0.489**	0.872***	-0.720***	0.899***	-0.712***
	(0.111)	(0.148)	(0.113)	(0.205)	(0.0776)	(0.120)	(0.0935)	(0.119)
dgdinsxinscl			-0.108				-0.0927	
			(0.172)				(0.134)	
cdum	-3.933***	2.771***	-3.630***	2.990***	-5.197***	2.429***	-5.171***	2.427***
	(0.145)	(0.175)	(0.149)	(0.166)	(0.130)	(0.142)	(0.134)	(0.144)
			-0.908***	1.376***				
Observations	12,339		12,339		11,016		11,016	
LL	-3198		-3193		-2978		-2977	

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

We continue by including continuous heterogeneity in consumer tastes and preferences in a mixed logit model. Further, we estimate this model directly in Willingness-to-pay space as recommended by Hole (2005). Given the large improvements in the likelihood, this becomes the primary model from which we draw conclusions from the willingness to pay data. Blueberry consumers continue to receive disutility, on average, from both GM plants and gene drive insect presence. However, the reduction in marginal willingness to pay for organic certification reduces slightly to 19.75%. For orange juice consumers, this reduction in marginal willingness to pay for organic certification reduces by half, to a statistically insignificant 10.7%. In this mixed logit specification, the general disutility from gene drive insects remains, even in high spray conventional systems. Therefore, the total change in willingness to pay for a pint of fresh organic blueberries declines by 39.8% and the decline in willingness to pay for a half-gallon of orange juice is a surprisingly similar 39.3%.